ICP Etching for the Fabrication of AlGaInN VCSELs using Pendeo-epitaxial Growth

H.-S. Kim+, T. Kim, I. M. Watson, R.W. Martin*, and M. D. Dawson
*Institute of Photonics & *Department of Physics, University of Strathclyde, Glasgow G4 0NW, UK*
+kim.hyeon-soo@strath.ac.uk

J. H. Marsh and R. M. De La Rue
Dept. of Electronics & Electrical Engineering, Glasgow University, Glasgow G12 8LT, UK

Currently, we are investigating approaches to electrical-injection AlGaInN VCSELs (Vertical Cavity Surface Emitting Lasers), where fabrication issues are very challenging. Our approaches to such VCSELs are based on the incorporation of SiO_2/ZrO_2 dielectric Bragg mirror elements into the device structure. We have proposed the use of overgrowth techniques to fabricate a high quality AlGaInN active region above a buried high-reflectivity dielectric DBR (Distributed Bragg Reflector) deposited after initial GaN growth on sapphire. A suitable buried DBR can be achieved using either lateral epitaxial overgrowth (LEO) or pendeo-epitaxial growth, simultaneously achieving the low defect density required by a high-quality microcavity active region. Previously, we have investigated the properties of the dielectric mirrors under epitaxial overgrowth conditions, and demonstrated the successful patterning of 10.5 pair mirror stacks into stripes suitable for LEO [1,2]. Dry etching will prove essential for the fabrication of AlGaInN VCSELs as it has for other optoelectronic devices, due to the practical inapplicability of wet-chemical etching to such alloys. In the present study, the challenging plasma etching issues related to the fabrication of AlGaInN VCSELs using pendeo-epitaxial growth are reported in detail.

As shown in Fig. 1, the buried dielectric DBRs are deposited between etched ridges of GaN prior to overgrowth by pendeo-epitaxy. In this approach, plasma etching is required to play an essential role in seed structure preparation for pendeo-epitaxial growth over dielectric mirrors, etch-back for microcavity length control, mesa formation for the n-type contact, etc.

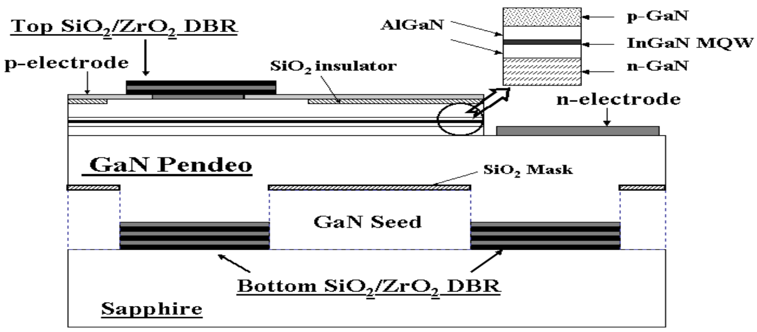

Fig.1. Schematic representation of the proposed VCSEL device, incorporating a bottom dielectric mirror buried by pendeo-epitaxial growth.

To investigate these issues, an inductively coupled plasma (ICP) system (STS Multiplex) has been used to etch III-nitrides. Process variables including the composition of $Cl_2/BCl_3/Ar$ gas mixtures, bias power, pressure, and total gas flow rate have been investigated for several structure geometries and layer combinations. Materials processed include p-GaN(Mg doping), n-GaN(Si doping), AlGaN and AlN, grown using MOCVD (Metal Organic Chemical Vapor Deposition). Patterned SiO_2 layers *were used* as etch masks and etch depths were measured using a step profilometer. Etch profiles and surface roughness were investigated using SEM and AFM, respectively.

Vertical side-wall etching has been achieved using $Cl_2/BCl_3/Ar$ plasmas, with a high etch rate of over 800nm per minute. Also, by optimizing pressure and gas-flow rate, full 2" wafers have been processed with excellent etch rate uniformity of <5%. An SEM image of undoped GaN etched under optimized conditions is shown in Fig.2.

Fig. 2. SEM image of undoped GaN etched in an 80%Cl_2/10%BCl_3/10%Ar plasma at 600 W inductive power, 300 W bias power, 10 mTorr pressure, and 50 sccm total gas flow rate.

In the fabrication of the GaN mesa structure, it is beneficial to design a process to etch through InGaN and AlGaN alloys with a singe etch recipe. Since GaN-based devices are based on heterostructures with a variety of compositions it is necessary to develop dry etching conditions which can effectively cover the entire composition range of $Al_xGa_{1-x}N$, and $In_xGa_{1-x}N$ alloys. In the current devices, the AlGaN layer is the etch rate limiting layer due to higher thickness compared to InGaN layer [3]. Figure 3 shows etch rates of undoped GaN, n-GaN, p-GaN, and undoped AlGaN as a function of Cl_2/BCl_3 mixtures. All of the III-nitrides showed a maximum etch rate in Cl_2-rich mixtures, and the etch rates of AlGaN were lower than GaN under all conditions. The etch rates of undoped GaN, n-GaN, and p-GaN were not significantly different, and showed a maximum near 90%Cl_2/10%BCl_3. In the case of AlGaN, the maximum etch rate was about 430 nm/min at 75%Cl_2/25% BCl_3, and further increases in BCl_3 flow rate decreased the etch rate.

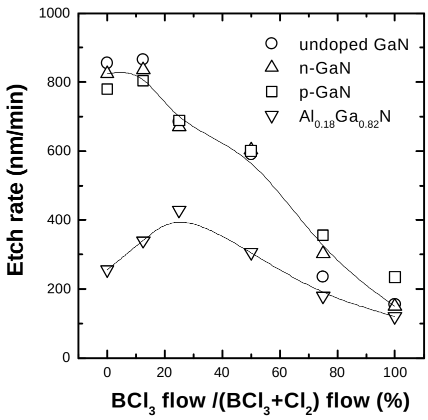

Fig. 3. Etch rates of undoped GaN, n-GaN, p-GaN, and AlGaN as a function of gas combination in a Cl_2/BCl_3 plasma at 600 W inductive power, 300 W bias power, 10 mTorr pressure, and 40 sccm total gas flow rate (lines are a guide to the eye only) .

In our proposed VCSELs, a vertical etch profile and smooth etched GaN surface are required to fabricate high-quality bottom DBRs. Prior to deposition of DBRs on patterned GaN, the surface morphologies of etched layers were investigated using AFM. These results were compared to non-etched surfaces. Finally, bottom SiO_2/ZrO_2 DBRs were deposited by e-beam evaporation on patterned GaN, etched under optimized conditions. SEM investigations of these pendeo-epitaxial seed structures incorporating bottom DBRs will be described.

References

[1] M. D. Dawson and R.W. Martin, British Patent Application 9807692.0 (April. 1998).

[2] R. W. Martin, T. Kim, I. M. Watson, M. D. Dawson, et. al, phys. stat. sol.(a), **176,** 67 (1999).

[3] H.-S. Kim, D. H. Lee, G. Y. Yeom, J. W. Lee, and T. I. Kim, Vacuum, **56**, 45 (2000).

Acknowledgement

This work was supported by U.K.' s EPSRC and SHEFC.